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Common Diseases of Cereals in Michigan

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Introduction

Although Michigan devotes large acreages to a wide variety of crops, the acreage devoted to and the income accruing from small grains and corn are considerable items in the agricultural industry. Though the acreage devoted to cereals and the income from these crops may fluctuate considerably during individual years, some idea of their place in the agriculture of the state may be obtained from the following table, taken from the Crop Report for Michigan, December, 1931.

Table 1.—Acreage, yield and value of Michigan cereal crops.

Crop	Acres	Yield in bushels	Value in dollars
Wheat	711,000	18,446,000	$9,234,000
Oats	1,435,000	43,768,000	10,504,000
Barley	278,000	7,228,000	2,891,000
Rye	158,000	2,133,000	811,000
Corn	1,407,000	40,944,000	16,378,000
TOTAL	3,989,000	112,519,000	$39,818,000

The cereal crops are subject to a number of diseases, some of which cause considerable loss each year, while others are of a serious nature only under exceptional conditions. In many instances, certain diseases are inconspicuous, causing only negligible losses locally but in the aggregate these may account for an appreciable loss to the crop as a whole. The practice of control measures not only reduces individual losses but serves to prevent the establishment of various plant parasites which eventually may make the growing of the crop unprofitable. Although the growing of crop varieties resistant to the various diseases may be the ideal means of prevention, such varieties are not available in all cases and various seed treatments have been devised to hold diseases in check.

In presenting the material in this bulletin, the writer has drawn freely upon State, Federal, and other publications to the authors of which the writer acknowledges his indebtedness, but many of the data on control are derived from personal investigations. Unless otherwise noted, illustrations are taken from photographs in the files of the Department of Botany and Plant Pathology.

WHEAT DISEASES

Stinking Smut or Bunt of Wheat

Tilletia laevis, T. tritici

Stinking smut of wheat annually is responsible for thousands of dollars loss in Michigan. The degree of infection may vary from a trace of the disease in certain fields to a high percentage of smutted heads in others. This loss can be prevented by proper treatment of the seed wheat before planting.

Of the smuts which affect wheat, the stinking smut or bunt causes the most serious losses. It not only reduces the yield of grain, but the presence of appreciable numbers of smut balls renders the grain undesirable for milling purposes. Smutted wheat must be thoroughly washed and scoured before being milled.

Two species of the stinking smut have been found in Michigan; namely, *Tilletia laevis* and *Tilletia tritici*. The former fungus is the common cause of stinking smut in Michigan, although wheat infected with *Tilletia tritici* has been found infrequently. These smuts caused by the two species are so similar that they need not be discussed separately.

Stinking smut in wheat is not readily detected until the plants are headed. Under certain conditions, however, infection may be evidenced by varying degrees of stunting of the plants and a somewhat darker blue-green color. In a later stage, the heads may also assume this characteristic bluish-green color. Such heads may be distorted or abnormal in shape or size. Often the glumes or chaff are spread apart by the growth of the smut balls which replace the normal kernels in the head, as shown in Figure 1. At this stage of development of the disease, the smut balls may often be seen through the glumes as black masses. When the heads mature, the darker smutted kernels are easily distinguished. The disease "stinking smut" takes its name from the fetid odor of decaying fish given off by the smut balls. This odor, due to the presence of trimethylamine produced by the smut fungus in the wheat kernel, is unmistakable evidence of the disease.

Stinking smut is caused by a parasitic plant or fungus which is microscopic in size. The spores of the smut fungus adhere to the wheat kernel and are planted with it. When the wheat seed germinates the smut spore (seed of the fungus) also germinates and sends its mycelium (roots) into the young seedling. The parasite then grows upward through the wheat stem keeping pace with the growth of the plant. When the young wheat kernel is forming in the head, the smut fungus makes a very rapid growth, feeding upon the food material of the young kernel, and replacing it with a mass of the black smut spores. In threshing, the smutted kernels or smut balls are broken and the spores of the fungus are thoroughly scattered over the otherwise clean grain. Many of the spores may remain in the thresher. Thus, although the wheat shows no stinking smut in the field, it may become infected after passing through a machine which immediately before threshed smutted wheat. Smut spores blown from the thresher fall to the ground and may be a source of the disease, but under Michigan conditions these smut spores usually germinate and die before the crop is planted. Only in one or two cases has stinking smut arising from infested soil been

known in the state. Storing clean wheat in old grain bags which previously held smutted wheat will also contanimate the seed.

Prevention of Stinking Smut

Fortunately, in the case of this disease, the spores of the stinking smut lodge upon the seed coat of the grain. In this location, they can be readily killed by treatment of the seed with some contact fungicide.

Fig. 1.—Stinking smut or bunt on wheat. Note spreading glumes and black smut balls replacing normal kernels in the head.

There are several treatments which are effective in controlling stinking smut. Those usually employed include copper carbonate, formaldehyde and organic mercury dusts. Copper carbonate is probably the most satisfactory material to use from the standpoint of cost, ease of application, and effect upon germination of the seed.

Formaldehyde is quite as effective in the control of stinking smut, but unless applied with the greatest care will cause serious injury to the seed. Many cases have come to our attention in which there was practically no germination of wheat due to improper treating with formaldehyde.

Certain organic mercury dusts have been used effectively against stinking smut. One of these dusts now marketed under the name of Ceresan has given practically complete control of the disease in our experimental trials. While higher in price than either formaldehyde or copper carbonate, it has the advantage of freely flowing through the drill under conditions of high humidity and unlike formaldehyde does not injure the seed with long standing after treatment. Ceresan is applied in the same manner as copper carbonate, at the rate of three ounces to the bushel after thoroughly cleaning the grain.

Directions for Treating

Copper Carbonate—Before treating, thoroughly clean the wheat in the fanning mill removing all smut balls. This step is absolutely necessary to insure effective control of the disease. Failure to remove smut balls will result in re-infection of the seed, and consequently a smutted crop. After treating, the grain must not be placed in sacks used for storing smutted grain. To disinfect the old grain sacks, soak two or three hours in a strong formaldehyde solution or new sacks may be used.

To be effective, each kernel must be covered with a thin film of the copper carbonate dust. The cleaned grain is then placed in a tight container or mixer, and the required amount of copper carbonate scattered over the surface of the grain. Copper carbonate, finely ground and prepared especially for seed treatment should be used. This can be obtained at local hardware and drug stores, elevators, or cooperative supply stores. In general, two grades of copper carbonate may be purchased, the full strength containing about 50 per cent, and the diluted containing about 20 per cent of metallic copper. The full strength (50 per cent of metallic copper) copper carbonate is generally more satisfactory than the diluted form. If the full strength copper carbonate is used, two to two and one-half ounces per bushel of wheat is sufficient. If the diluted copper carbonate is used, it is necessary to add from three to four ounces to each bushel of wheat to give the best results. The container or mixer is rotated slowly 50 times or from two to four minutes. This insures the thorough coating of the seed with the copper carbonate. The treated grain may be stored without injury until ready for planting.

Do not mix by shovelling the grain into piles nor by adding the copper carbonate to the grain in the drill box. These methods will not give satisfactory control of stinking smut.

Homemade Oil Drum Mixer

A revolving churn or large milk can may be used for treating small lots of wheat. For larger quantities, much better results are secured and the labor lessened by using a mixing machine. A concrete mixer may be used

if the mouth of the drum is covered with canvas to keep in the dust. Although several commercial mixing machines are available, a satisfactory machine may also be made at small cost. A homemade mixer can be constructed from a 30 gallon oil drum or small wooden barrel. The oil drum is preferable because of its lesser bulk and lighter weight.

If the oil drum is to be used, cut out half of one head. Bolt to the top of the remaining half a 1 x 6 inch board to fit the opening snugly against the inside rim of the barrel. Cut a semi-circular head to fit the open half of the drumhead and hinge this to the 1 x 6 inch strip. The door may be made dust tight by nailing a strip of an old inner tube to its edge. The door is held tightly against the edge of the drum by means of a hasp.

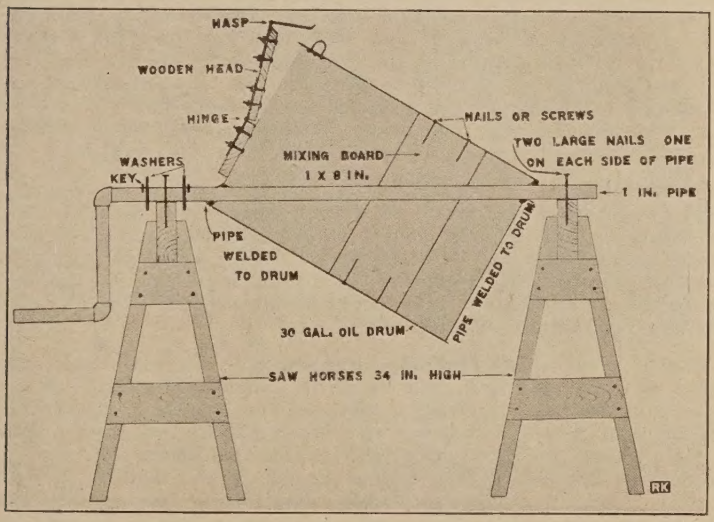

Fig. 2.—Working drawing of oil drum mixer for treating seeds with dust disinfectant. (After R. S. Kirby, Cornell University Extension Bulletin 157.)

The axle, threaded at one end, is made of three-fourth-inch pipe 48 inches long, and passed diagonally through the barrel extending about 8 inches beyond each end. The axle may be welded or bolted to the drum. The handle is made of two 12-inch lengths of three-fourths-inch pipe joined together and to the axle by means of two elbows. A mixing board 1 x 6 inches is placed across the full inside width of the drum and held in place by nails or screws. Mount the mixer on sawhorses about 32 inches in height. The drawing plan of the oil drum mixer is shown in Figure 2.

The barrel mixer is made in a similar manner using a 30-gallon wooden barrel with the axle passing through it lengthwise. In this case, the door is cut in the side of the barrel. Either of these mixers is easily and cheaply made and insures thorough mixing of grain and chemical dust.

Drill Injury and Rate of Seeding

Wheat dusted with copper carbonate does not feed through the drill as freely as untreated seed. However, the small decrease in rate of seeding is compensated for by the greater tendency of the plants to stool and by the production of larger heads, because of the greater space between plants. When the rate of seeding is six pecks per acre or less, it may be advisable to increase the rate of seeding by one peck per acre.

Certain growers have reported difficulty in seeding copper carbonate treated wheat due to the clogging of the drill. This difficulty often follows when the drill containing the treated wheat is allowed to stand out-of-doors and the grain, moistened by dew or rain, becomes packed. Care should be taken that the grain is not allowed to stand in the drill out-of-doors in rainy weather or during heavy dews. If the grain does become wet, it should be thoroughly stirred before sowing. Also, the gears should be loosened by rocking the drill wheel back and forth by hand or by turning the feed shafts with a wrench before throwing the drill into gear. After sowing copper carbonate treated wheat, the drill box, cups, and feed pipes should be cleaned by blowing or by running dry untreated seed through the drill. Keep the gear bearings well oiled during sowing. These precautions will prevent twisting or breakage of the feed shafts of the drill.

Formaldehyde—The formaldehyde treatment, while as effective as copper carbonate in the control of stinking smut is the least desirable of the control methods and must be used with considerable care to prevent seed injury. Formaldehyde is not recommended for use on wheat when copper carbonate is available. Two methods of treating are commonly employed in certain sections of the state: (1) the dilute formaldehyde, and (2) the concentrated formaldehyde method.

Dilute Formaldehyde Method—Clean the grain thoroughly to remove light seed and smut balls. Place the seed in piles and sprinkle until every kernel is thoroughly wet, using a solution of one pint of formaldehyde in 40 gallons of water. One gallon of solution will treat about two bushels of grain. Cover with blankets or bags for only **two hours,** then spread out thinly in a warm place to dry. Sow at once or not later than 12 hours after treating. The drill should be set ahead to allow for the slightly swollen grain. Do not sow in dry soil.

Concentrated Formaldehyde Method—Clean the grain as recommended above. Apply the formaldehyde with a hand sprayer as the grain is being shoveled from one pile to another. Use one pint of formaldehyde diluted with four or five pints of water to treat 50 bushels of grain. Cover with sacks or blankets **four hours—no longer.** Spread the grain thinly in a dry warm place and allow to air for one or two hours. Plant immediately. Do not treat more grain than can be sowed in one day. This treatment will severely injure or kill the seed if it is kept overnight. Do not sow formaldehyde-treated wheat in dry soil; to do so will result in decreased stand due to injury to the seed.

Resistant Varieties

At the present time, one variety of wheat highly resistant to stinking smut under Michigan conditions has been developed by the Plant Breeders of the Experiment Station. This variety is Berkeley Rock and requires no treatment for stinking smut. Further work is in progress to develop more de-

sirable and better yielding resistant varieties suitable to the growing conditions of the State.

Loose Smut of Wheat

Ustilago tritici

The loose smut of wheat, although far less destructive in this State than bunt or stinking smut, is more easily recognized in the field. More than 5 per cent infected heads in a field is rarely seen, and usually the percentage of infection averages much less.

Fig. 3.—Loose smut of wheat.

Loose smut is first seen when the infected plants head out. Instead of the normal glumes and flowers as seen in healthy plants, these organs are replaced by the mass of black dusty smut spores. The entire head or only part of it may be affected. This characteristic effect of the smut fungus shown in Figure 3, has led to the name "black head" for the disease. The black spores are easily displaced and soon after the heading of the grain they may be blown or shaken off by the wind or washed away by rain leaving only the naked rachis.

The dissemination of the spores takes place concurrently with the blossoming of the healthy plants. Loose smut spores scattered by wind, rain, or insects fall upon the stigma or ovary of the open healthy flowers. Here, if sufficient moisture is present, they germinate and grow into the young developing wheat kernel. Since, in Michigan, the heading of the wheat and dispersal of the smut spores may take place during relatively dry weather, this may contribute to the comparatively little infection from loose smut. In addition, severe winters tend to kill out the smutted plants. The loose smut fungus, unlike that of bunt or stinking smut, does not destroy the seed. After penetrating into the ovary, the fungus becomes inactive, lying dormant in the kernel until the wheat seed germinates. With the germination of the wheat seed, the loose smut fungus also begins to develop, keeping pace with the growth of the plant, and replaces the flowers with a mass of spores thus completing its life cycle.

Because the loose smut fungus lies dormant in the seed, it is impossible to distinguish between mature healthy kernels and those infected with the loose smut. Seed secured from fields showing an appreciable amount of loose smut will usually produce a smutty crop of wheat unless properly treated.

Control of Loose Smut

Since the loose smut fungus is carried within the wheat seed, it is readily seen that contact fungicides, such as those applied to the outside of the seed for the control of stinking smut, will not effectively control loose smut. In this case, it is necessary to employ a treatment which will kill the fungus within the kernel without serious injury to the seed. The hot water treatment has been found the most effective for loose smut. Two methods of treating are available; namely, the modified and single bath methods. If the seed is infected with stinking smut as well as loose smut, this treatment will control both diseases at the same time.

The Modified Method—Place the wheat seed in a loosely woven bag, filled half full and tied at the top. Soak four hours in cold water. The half-filled bag allows for swelling of the grain. Remove from cold water and immerse momentarily in water at about 120° F. This dipping warms the grain slightly, preparatory to the final soak. Soak 10 minutes in water at 129° F. Remove from this bath and spread the grain in a thin layer to dry.

Single Bath Method—Fill sacks half full and tie tightly at top. Soak 1 hour and 35 minutes in water at 120° F., or soak 1 hour and 50 minutes at 118.5° F. Spread grain in a thin layer to dry.

In both methods, it is essential that the water of the 10-minute bath be held as nearly as possible at the designated temperature. If the temperature falls too low the treatment will not affect the smut fungus; should the temperature rise too high, the wheat is killed. It is safe to allow a variation of three degrees above or below the temperature required, provided such variation is of only a few seconds duration. Stirring the water during the soaking period will facilitate keeping the temperature constant.

The hot water treatment is best employed where live steam or hot water and vats are available. For this purpose, the facilities offered by creameries have been found very satisfactory.

Limitations of the Hot Water Treatment

Because of the difficulty of maintaining constant temperature in the water bath over long periods of time, these treatments are not usually recommended for the individual grower. Neither method is recommended for the treatment of sufficient seed to plant the entire crop. The treatments are rather difficult to make and, in addition, cracked or broken grain will be injured or killed by the treatment. The treatments can be made on a community basis, where facilities are available, each grower treating sufficient seed for a seed plot. The treated seed should be planted in a plot isolated as far as possible from other fields of untreated wheat. The seed from the plot of treated grain and subsequent crops from the same seed should remain free from loose smut for several years under Michigan conditions. This treatment is especially recommended for seed plots of certified wheat.

Since the hot water treatment causes considerable injury to the seed, this should be taken into account when planting and about one-third more per acre added to the amount sown.

Best results are secured when the treated seed is spread in a thin layer and thoroughly dried before planting. Care must be exercised to prevent moulding or sprouting of the seed while it is drying.

Resistant Varieties

A number of varieties and strains of wheat resistant to loose smut have been developed by investigators of the U. S. Department of Agriculture and several state experiment stations. Among these may be mentioned Blackhull, Hussar, and Ridit, (hard, red, winter common wheats); Russian, Trumbull, Wyandotte, Fultz, Fulcaster, Harvest Queen, Leap, Purplestraw, Gipsy, and Forward (soft, red, winter common wheat); Preston (hard, red, spring common wheat); and certain varieties of white, winter common wheat. At the present time, Berkeley Rock is the only variety of wheat (semi-hard, red, winter) developed by the Michigan Agricultural Experiment Station which appears resistant to loose smut and is grown on a commercial scale in the State. This variety has the added advantage of high resistance to stinking smut as well. Several other varieties or selections also show considerable promise of resistance in field trials, but are not now produced upon a commercial basis.

Scab of Wheat

Gibberella saubinetii

The scab disease of wheat occurs sporadically throughout the State when weather conditions are favorable. Barley, rye, oats, and corn are also affected. The disease occurs as (1) head blight and (2) seedling blight.

Head blight, the more noticeable form of the disease is seen during periods of moist weather during heading and maturity of the grain. The spikelets, all or in part, lose their green color and finally turn straw color (Figure 4). A salmon-pink or reddish fluffy or dusty growth of the fungus is apparent at the base of the spikelets or along the edges of the glumes. At this stage, the summer spores are produced. During periods of protracted humid weather, the fungus may spread to include the entire head. The kernels, heavily infected by the scab fungus, shrivel and may be killed. Such kernels also show the typical fungus growth. In addition, small black bodies appear on the infected kernels, as seen on barley in Figure 16. These are *perithecia,* the bodies containing the winter spores. Under less favorable conditions, only one or a few spikelets are so affected and the kernels are only partially infected. The stems of the plant as well as the heads may be infected, furnishing a source of infection for next year's crop.

Infected kernels when planted give rise to the second form of the disease; namely, seedling blight. Seedling blight may take place also when clean seed is planted in infested soil. The fungus is most active during and following the germination of the seed. Oftentimes, the seedling is blighted or killed before it emerges from the soil. Should the fungus attack be less severe, the seedling emerges but shows lack of vigor and pale green to yellow leaves. In such cases, one finds a reddish brown rotted area on the underground plant parts as shown on oats, Figure 10, page 27. Many of these seedlings fail to mature or produce stunted plants with small heads and light weight kernels or the heads may fail to fill. Blight and root infection of mature plants is common in the state.

As indicated, the scab fungus has two stages in its life cycle; namely, the summer or conidial stage known as *Fusarium graminearum* and the winter or ascigerous stage known as *Gibberella saubinetii.* The reddish fungus growth (summer stage) on the wheat heads gives rise to enormous numbers of conidia. These are scattered by the wind and splashed in water

drops to healthy heads, thus spreading infection. After a short period, the reddish fungus growth gives rise to small black spherical bodies readily seen with the unaided eye. These structures are the *perithecia,* small flask-shaped bodies partly buried in the tissues of the kernel, stems, or chaff. Within these bodies, the winter spores or *ascospores* are borne. In this manner, the parasite lives through the winter and until late spring or early summer. With warm moist weather, the winter spores are shot out of the perithecia and fall upon the young heads of grain where they produce the summer stage of the fungus. It is largely from the winter stage of the fungus on infected grain and cornstalks that the scab disease gets its start in the grain field. A more detailed account of the scab fungus on corn is given under the heading "Gibberella ear rot," page 47. The symptoms of the disease on barley, oats, and rye are also given under these crops, pages 36, 27, 44.

Fig. 4.—Head blight stage of wheat scab. Upper portion of heads straw color with shrunken light weight kernels.

Provided a source of the fungus, warm moist weather, gentle rains or heavy dews, during the flowering and heading of the grain are conducive to scab infection. Under these conditions, spores of the fungus formed on wintered-over infected corn stalks, stubble or straw are blown to the developing heads. With continued moist warm weather, the summer spores are produced in abundance and are blown about the field to produce abundant infection. Dry weather during this period prevents largely the dissemination of spores of either kind and little or no scabbing of the grain results.

The primary sources of seedling blight are infected kernels planted with the seed and from infected straw, stubble and corn stalks left uncovered in the grain field. Seedling blight is favored by a cold dry soil which is unfavorable to the growth of the seedling. Blight is of little consequence to the seedling which germinates and grows with normal rapidity. Sowing on heavy unplowed stubble land or land improperly fitted is poor economy as it usually slows germination and retards growth of the seedling, thus making it subject to attack. Sowing in infected unplowed corn or grain stubble also places the grain in the midst of the source of scab infection. In a wheat disease survey of southern Michigan in 1930, one of the worst cases of scab seen was in wheat sowed in unplowed corn stubble which was heavily infected with the scab fungus. In this field, about 75 per cent of the wheat heads were scabbed.

The dry weather conditions such as occurred in Michigan in 1930 and 1931 were generally unfavorable for scab infection. The disease is usually not severe over the entire State in any year. These conditions make easier the control of the disease. As the first step in control, the old infected stubble and straw should be plowed under and thoroughly covered. Furthermore, if the corn crop shows an appreciable amount of Gibberella ear-rot, rotate crops so that small grain does not follow corn immediately. Thoroughly fit the land to give the best conditions for seed germination and seedling growth. Sow varieties adapted to soil and locality. Use scab-free seed or seed which, as far as possible, has been thoroughly fanned and cleaned to remove the light scabby kernels. Treat the seed if it is suspected of coming from a crop which showed scab infection.

For seed treatment, Ceresan, an organic mercury dust has proved effective against scab. Copper carbonate, used for the control of stinking smut, is not effective against scab. The formaldehyde treatment, page 8, while effective against seed infection, may cause very serious injury to the grain unless used with the greatest caution. Should the wheat seed be infected with scab and stinking smut, both diseases may be controlled at the same time by treating with either Ceresan or formaldehyde as given on pages 6 and 8.

Resistant Varieties

Several varieties of wheat, including Minturki and Red Rock (winter wheats) and the spring wheat varieties Norka, Progress, Resaca, and selections from Illinois No. 1 are reported to show resistance to scab. Red Rock, developed at Michigan State College is widely grown on a commercial scale in the State.

Stem Rust of Wheat

Puccinia graminis

Stem rust, prevalent throughout the State and found on all commercial varieties of wheat, may cause considerable loss in individual fields. The total loss in the State due to this disease over a period of years, however, averages less than 1 per cent annually.

The fungus causing stem rust has a rather complex life cycle. The spring stages of the rust occur upon the leaves of the common barberry (*Berberis vulgaris*) and certain species of Mahonia. The summer and winter stages occur on wheat, barley and certain wild grasses. The rust passes through three stages as follows:

Spring Stage—Stem rust is first seen in early spring upon the leaves of the common barberry. The time of its appearance depends largely upon weather conditions. Small yellow pustules (pycnia) later becoming black, are first observed upon the upper surface of the barberry leaves. This is the pycnial stage. A little later, larger orange yellow pustules appear on the under side of the leaves. These spots are made up of numerous small cup-like structures, the *aecia* containing the *aeciospores* or spring spores. The cups break open and the masses of yellow spores are scattered to the young growing grain and wild grasses near by. Falling upon the wheat plant, the aeciospore sends its infection thread into the plant giving rise to the summer stage of the rust.

Summer Stage—This stage of the rust, usually referred to as the "red rust" is easily distinguished from other rusts by the production of elongated reddish brown pustules (uredinia) under the epidermis. Stems, leaves, glumes, and awns may be affected. Usually the greatest numbers of pustules are found on the stems and leaf-sheath. As the fungus develops, the pustule pushes outward and finally breaks through to the surface and exposes the reddish brown dusty mass of spores, the *urediniospores*. Often, portions of the broken epidermis adhere to the edges of the pustules, giving a scaly appearance to the stem. Moist warm weather is favorable to the development of the red rust stage and under suitable conditions new crops of spores may be produced and new infections take place at intervals of 10 to 18 days throughout the growing season. As the grain matures, the red rust stage gives rise to the winter stage of the rust.

Winter Stage—The winter stage of the rust is commonly known as the "black rust," (Figure 5) because of the black pustules, *telia* formed upon plants showing the summer or red rust stage. The black rust stage follows the red stage in the same pustule or sorus. Upon close examination, both red and black stages of the fungus may be found together or the latter appears at the edge of the red rust sorus. The black stage is made up of millions of brown spores, the *teliospores*. The teliospores pass the winter on old infected stubble and refuse in the grain field or upon infected wild grasses. In the early spring, with the advent of warm moist weather, the winter spores or teliospores germinate in the black pustule, sending out minute stalks upon each of which are borne four *sporidia*. These are blown by wind to the barberry or Mahonia leaves. Here, they germinate and, penetrating the leaf, reproduce the spring stages (pycnia and aecia) of the stem rust, completing its life cycle.

In Michigan and other northern states, it has been definitely proved that the initial infection of wheat and other grains comes principally from rusted barberries. This fact establishes the seriousness of the common barberry as a pest. Since 1918, concerted effort of state and federal forces has been directed at the complete eradication of the common barberry as protection against stem rust epidemics. During this period, more than five and one-half million common barberry bushes have been destroyed in Michigan. Many bushes have sprung up from seeds dropped in inaccessible places by birds or carried there by animals. It will take several years of careful searching before these and other bushes are found and destroyed. At present, systematic effort is directed toward finding and removing barberry bushes in areas devoted largely to the production of grain crops.

The stem rust parasite, unlike many other fungi which attack plants, is highly specialized. While the stem rust on wheat, oats, rye, and timothy appears to be identical, it has been found that the forms upon each of these plants are very specific in their ability to cause infection. The stem rust on wheat does not infect timothy and vice versa. The form on rye does not infect timothy, wheat, or oats. Because of this pecularity in the habit of the rust parasite, the forms which appear identical but which show specialization in the plants they attack are known as *physiological forms* of stem rust. To indicate which physiological form is being dealt with, a variety name is added to the name of the stem rust fungus. For example, the stem rust fungus is *Puccinia graminis*. If the rust occurs on wheat, the variety name is indicated by the addition of *tritici* showing that the principal grain attacked is wheat, *Triticum spp*. The name of the stem rust on wheat then becomes

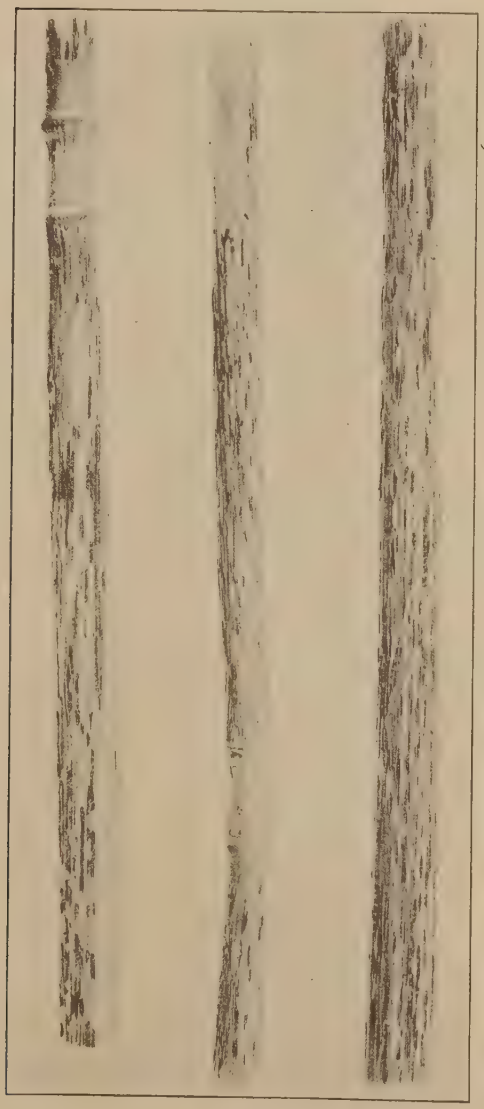

Fig. 5.—Winter or telial stage of wheat stem rust. This stage of the rust follows the "red rust" or summer stage in the same pustules.

Puccinia graminis tritici. The physiological forms of stem rust with the principal plants attacked are as follows:

1. *Puccinia graminis tritici* attacks wheat, barley, rarely rye, and many wild grasses including wild rye, brome, and wheat grasses and squirrel tail grass.
2. *Puccinia graminis avenae* on oats and certain wild grasses such as orchard grass and meadow fescue.
3. *Puccinia graminis secalis* attacks rye, barley, quack grass, and other wild grasses.
4. *Puccinia graminis phleipratensis* found on timothy, sometimes as a weak parasite on oats, rye, barley, and fescue grass (Festuca spp.).
5. *Puccinia graminis agrostidis* attacks species of bent grass (*Agrostis canina* and *A. stolonifera*).
6. *Puccinia graminis poae* occurs on the blue grasses *Poa compressa* and *P. pratensis.*

The situation is further complicated by the occurrence of **biological species** of rusts within the physiological forms. Investigations, particularly in Minnesota, have shown that there are about 60 biological species of the stem rust *Puccinia graminis tritici* in North America. These biological species of stem rust, while appearing identical under the microscope show definite variation in their ability to infect different types and varieties of wheat. This peculiarity of the stem rust parasite has made the breeding of resistant wheats a very difficult problem. It has also been found that the common barberry is essential in originating new biological species. Varieties of wheat resistant to the biological species of stem rust in one locality may be severely attacked by another biological species when grown only a short distance away.

Since the stem rust is not carried on the grain seed, treatment is of no value in control of the disease. Spraying is impractical because of the character of the crop. Dusting with finely ground sulphur has been found effective on small experimental plots and on very large acreages in the western states where the material can be applied by airplane. For the Michigan wheat grower, removing the primary source of stem rust infection, the common barberry, and planting early maturing varieties or those showing resistance to the disease on well drained soil appear to be the most practical means of control. Experimental work being carried on by the Plant Breeders of the Experiment Station indicate certain varieties highly resistant to stem rust. Hybrids and selections are being developed to obtain resistant varieties having suitable growth and yield characters and milling qualities. Such varieties are not yet produced on a commercial scale.

Spot Blotch of Wheat

Helminthosporium sativum

Spot blotch of wheat is widely distributed in Michigan and under favorable conditions for the development of the causal fungus may cause considerable injury to stand or yield in individual fields. The average annual loss to the crop for the entire State, however, is probably less than 0.5 per cent.

This disease may affect the roots, stems, leaves, and heads of the plant. Affected seedlings show typical blighting. In some cases, the small plants rot at the ground line, in others the seedling may fail to push entirely through

the soil. When roots are attacked, they are partially or wholly rotted, stunting or killing the seedling. Infected seedlings which survive often show the typical large dark reddish brown spots on the first or second leaves. Affected leaves may curl or twist or the leaf blade may break in two at the lesion.

On older leaves, the disease appears as numerous dark reddish brown blotches oval or irregular in outline often involving a portion of the midvein. Similar spots may be produced on the leaf sheath, stems, glumes, awns and the base of the seeds. Heavy infection of the heads may result in failure of seeds to develop or in the production of light weight discolored kernels. The disease also affects many of the wild grasses as well as barley and rye. One strain of the fungus isolated from wheat in the College experimental plots was particularly virulent upon wheat seedlings but less so on barley and failed to infect oat seedlings.

This disease often gains entrance to a wheat field in infected seed. When such seed is planted early in the fall in warm (60° F. or above) moist soil, the fungus becomes active with the germination of the seed. Seedlings not entirely killed may have several leaves affected, thus carrying the parasite over winter. Further infection in the spring results from the scattering of spores of the fungus which wintered over on the seedling leaves. During the growing season, there may be several series of new infections coming from the originally infected or other diseased wheat plants, or from infected grasses near the wheat field. There are about 33 species of wild grasses which also are attacked by this disease. Since infection on wheat may take place almost to maturity, there is ample opportunity for the seed to become diseased.

Not only does this fungus life over winter in the dry seed, in dead infected wild grasses, and leaf spots on diseased seedlings, but it may also live for several months in the soil. The problem of control therefore resolves itself largely into means of preventing the disease from gaining a foothold in any locality. Healthy seed is essential; thoroughly cleaned seed will eliminate many of the light weight shriveled diseased kernels. Proper rotations in which neither rye nor barley follows wheat should prevent soil infection to a large extent. Late fall planting, after the soil temperature is 60° F. or below, will do much to prevent rapid development of the parasite in the seed. It should be borne in mind in this connection that extremely late planting of winter wheat is also more conducive to infection by the stinking smut. Seed treatment will reduce initial infection from diseased seed. Preliminary trials show that an organic mercury dust, marketed commercially as Ceresan, while not completely effective, reduced seedling blight to a very small percentage. This material may also be used as a treatment for the prevention of stinking smut, page 4.

Prolonged soaking of the seed in formaldehyde also will materially reduce the disease on seedlings. This treatment too often results in serious injury to germination and is not recommended. The hot water treatment, page 10, is effective against spot blotch on wheat seed as well as the loose and stinking smuts.

Powdery Mildew of Wheat

Erysiphe graminis

This disease is found throughout the State on wheat, oats, barley, and rye. While there is no doubt that it causes some reduction in yield during certain seasons, the extent of such losses is usually slight and difficult to determine.

Reduction in yield is brought about by killing of leaves and decreased leaf area for the manufacture of food materials and by direct infection of the head causing destruction or in light attacks, shrivelling of the grain.

Infection may become severe in the spring but usually the disease is most abundant just previous to heading. The disease is first evident as a small grayish spot on the upper surface of the leaf. This spot enlarges and becomes covered with the grayish moldy growth of the fungus. At this stage of growth, the fungus produces large numbers of conidia or summer spores. These are scattered by rain and wind to neighboring plants rapidly reproducing the disease. The conidia, falling upon other leaves, germinate and send out slender threads over the surface of the leaf tissue.

Small suckers or haustoria are formed on the external threads and these, penetrating the leaf tissue, draw food from the plant for the support of the fungus. With continued growth of the fungus, the affected leaf gradually turns yellow first beneath the infected spot and later extending outward involving a considerable portion of the leaf. Finally death of the infected part results.

After several crops of summer spores or conidia are produced, the winter stage of the fungus develops within the same infected spots. The grayish mold-like growth of the fungus is seen to be dotted with very small black bodies, the winter spore cases or *perithecia*, as shown in Figure 6. Within these perithecia the winter spores, *ascospores* are formed. In this stage, the powdery mildew parasite lives over winter. In the following spring, with the advent of warm moist weather, the spore cases break open, discharging the ascospores. These fall upon the leaves of the young wheat plants, germinate and reproduce the summer stage of the fungus.

Wheat, barley, oats, and rye are affected by this disease. However, the fungus which attacks one of these cereals, will not also attack any of the others. This is one of the best examples of a high degree of specialization among the plant parasites.

Powdery mildew may readily be controlled by thorough dusting with sulphur. This method however is impractical on a commercial scale but may be used on small plots of wheat grown for special purposes. Resistant varieties have been developed in certain areas where the disease causes severe losses. Under Michigan conditions, the losses caused by the disease have not warranted control measures by either means.

Leaf Rust of Wheat

Puccinia triticina

Leaf rust is prevalent wherever wheat is grown in the State. In epidemic years, the loss due to this disease may be severe in local areas, but usually it averages less than one per cent of the crop. Badly infected plants produce fewer kernels of smaller size and less weight. Heavy infection of the plants in early seedling stages of growth may result in decreased stands and failure to produce seed.

As indicated by the common name, this rust affects principally the leaves of wheat, although it may be found to a small extent on the stems and heads. The disease is first seen as small, oval orange spots scattered usually on the under side of the leaves. The rust passes the winter in the summer or uredinial stage because of which heavy infection may take place early in the summer. Development and dissemination of summer spores with consequent increased

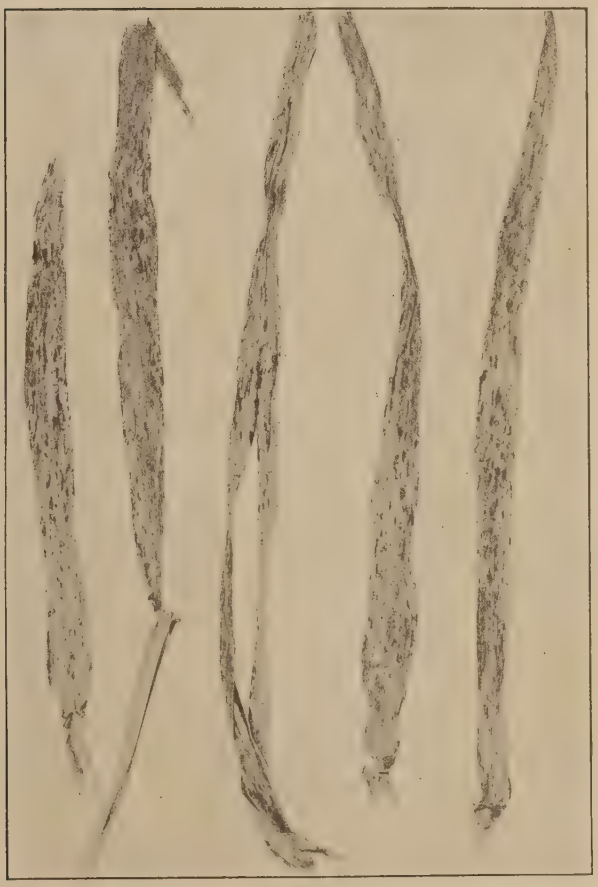

Fig. 6.—Winter stage of wheat powdery mildew. Note the black perithecial bodies scattered over the leaves.

infection may take place throughout the growing season until the wheat begins to mature. At this time, the winter stage of the rust is formed as small, black, flattened pustules beneath the epidermis. The spring stage of the rust is found on meadow rues (*Thalictrum* sp.) but it is not necessary in the propagation of the parasite.

In certain states where the disease causes severe losses, resistant varieties of wheat are being developed. The rust apparently is of less importance in Michigan.

Ergot of Wheat

Claviceps purpurea

Ergot of wheat occurs in the State but the percentage of infected kernels is so small as to make the disease of no importance economically. The appearance of the disease on wheat is similar to that on rye and the reader is referred to page 39 in the bulletin.

Anthracnose of Wheat

Colletotrichum graminicola

This rather inconspicious disease has been found in many wheat fields of the State. The damage it causes however is relatively slight in most cases. Where wheat is planted on heavy, poorly drained soil, severe injury may result.

Leaves, stems, glumes, and seeds of wheat are affected. The disease is first seen as the grains begin to fill. At this time, badly affected plants appear to ripen prematurely and the heads become bleached in appearance. This blighting of the heads may result in shriveling of the grain. In addition, water-soaked, purplish blotches appear on the stems at or near the nodes, later as the plant matures, the affected parts show numerous very small, black, raised bodies, the fruiting bodies of the parasite. Spores formed in the black spots (*acervuli*) are splashed and blown from affected to healthy plants, falling upon the seeds. The parasite lives over winter either as spores on the outside of the wheat seed or within the shriveled light-weight kernels in the form of infection threads (*mycelium*). It may also live from year to year on infected stubble, straw and probably certain wild grasses.

Thorough cleaning of the seed will eliminate most of the shriveled light-weight kernels. Planting on well drained soil also aids in preventing the disease. Seed borne spores may be killed by a surface disinfectant but this will not eliminate infection from mycelium within the kernel. Being of minor importance little work has been done upon various phases of this disease and adequate control methods have not been developed.

Barley, oats, and rye are also attacked by the anthracnose parasite. In each case, the losses are very small, the symptoms of the disease are very similar and the life cycle of the causal fungus the same. Control of the disease on these cereals is also imperfectly developed.

OAT DISEASES

The Smuts of Oats

Probably the most common of our cereal diseases is smut in oats. Annually the oat smuts take their toll in spite of the fact that they are easily prevented.

There are two distinct fungi responsible for the oat smuts. Although the two diseases may appear identical at a glance, with closer observation they readily can be distinguished as (1) the loose or naked smut and (2) the covered smut. Both smuts are common in Michigan, and may occur at the same time in an affected field of oats, and are about equally serious. Although caused by distinct fungi, both smuts are controlled by the same treatment.

Loose Smut of Oats

Ustilago avenae

The loose smut is first seen as the heads of oats emerge from the boot. The head is usually completely destroyed, the oat kernels being replaced by the brownish powdery mass of smut spores. The disease in this stage is shown in Figure 7. At first, the spore mass is enclosed by a thin membrane. This early breaks away allowing the spores to be blown to neighboring healthy heads where they lodge on the glumes or between the glumes and young kernels. Here, the spore may germinate and penetrate the glume or lie dormant until the oat seed is planted. When the oat seed, harboring spores or mycelium, germinates, the smut fungus also develops and infects the young seedling. The fungus, established within the seedling, keeps pace with the growth of the plant, replacing the normal oat kernel with the characteristic brown mass of spores.

Fig. 7.—Loose smut of oats. Early stage.

While there are several materials now upon the market for preventing oat smut, formaldehyde solution is at present the most economical to use. Treatment with formaldehyde, if properly carried out, insures a crop of clean oats.

Sprinkling Method—With this treatment, one pint of formaldehyde is added to 40 gallons of water (or in this proportion) and the oats are thoroughly wet by sprinkling. Use at least two quarts of solution per bushel of grain. Shovel the wet grain into a pile and cover two to eight hours with clean sacks, blanket or canvas; then spread out thinly and allow to dry. Do not allow treated grain to freeze or sprout. In planting make allowance for the

slightly swollen grain. If the grain is not planted promptly after treatment, it should be spread out in a thin layer to air and raked at intervals to prevent seed injury.

Spray Method—The grain is treated with a more concentrated solution than is used when sprinkling. One pint of formaldehyde is added to four or five pints of water (or in this proportion) and used to spray 50 bushels of grain. Spray the grain as it is shoveled from one pile to another, using a small hand sprayer. If the sprayer is held close to the grain during the operation, there is less irritation from the formaldehyde fumes. Treat, if possible, in a room with good ventilation or a strong draft. Cover the treated grain four hours with clean sacks or blankets; then spread out thinly to dry. Rake over several times while the grain is airing. If not sown at once, rake at frequent intervals until ready for planting or the grain is completely dry.

Sacks may be disinfected by dipping them in a solution made up of two tablespoonfuls of formaldehyde added to three gallons of water. This treatment will kill the wheat, oat, barley, and rye smut spores.

The formaldehyde treatments are recommended for hulled oats; for hulless oats, use the copper carbonate treatment as given for stinking smut of wheat, page 6.

Dust Treatments—There have been placed upon the market several dusts containing some form of formaldehyde or organic mercury as the active fungicidal ingredients. Of these materials, those marketed under the trade names of Smuttox, Ceresan, and Corona Oats Dust have been tried out in test plots. All of them gave good control of oat smuts, but they are no more effective than the formaldehyde solution, and they are more expensive to use at the present time. For the grower who does not wish to use liquid formaldehyde because of its irritating qualities, these dusts may be substituted with safety.

Apply the dusts to the grain, as recommended on the label, in a tight container. Rotate the container about 50 times until every kernel is thoroughly covered. The drum mixer shown in Figure 2 may be used for dust treatment of oats. After treating, the grain should be held in bags for at least five hours or better still, over night before planting. Treated grain may be held several days in loosely woven bags without injury to germination.

Covered Smut of Oats

Ustilago levis

Covered smut when first seen on the emerging oat head has much the same appearance as loose smut. The infected plants are usually somewhat stunted and the heads are often partly enclosed by the leaf sheath, in contrast to those affected with loose smut. Covered smut does not so completely affect the head or panicle, the outer glumes being only partially destroyed, thus serving to enclose the spore mass. Two plants affected with covered smut are shown in Figure 8. The spore mass, enclosed by its membrane, persists throughout the period of ripening, and is broken during threshing, when its spores are scattered to the healthy oat kernels. The spores of the covered smut are smooth, while those of loose smut appear finely echinulated or dotted.

The covered smut spore falling upon the oat grain lies dormant until the seed is planted. When the oat seed germinates, the spore germinates also, infecting the young seedling, the fungus mycelium keeping pace in growth with that of the plant and finally replacing the kernel with black or purplish-black mass of spores covered by a thin membrane.

Fig. 8.—Covered smut of oats. Note the black spore masses within the glumes.

Control of Covered Smut of Oats

All the treatments given for the control of loose smut of oats are usually effective for the covered smut, see page 21.

The Markton variety of oats is very resistant to both loose and covered smut. This variety, however, lodges more readily than Wolverine, a widely grown Michigan oat, and therefore is adapted only to our lighter soils. Trials with smut-resistant crosses of Markton with other varieties better adapted to Michigan conditions are being carried on by the Farm Crops section of this Experiment Station. At present, none of these resistant crosses are grown on a commercial scale for distribution.

Leaf Spot of Oats

Helminthosporium avenae

Although this disease occurs in many oat fields throughout the State, its more exact occurrence and the damage done to the crop is not known. The fact that the effects of hot dry weather may mask the symptoms of the later stages of the disease makes it almost impossible to distinguish between the two conditions in the field.

The disease is apparent on the first leaf of seedling oats. Here the spots, one to three or four in number, are irregular or oval in outline and dark reddish brown in color. The early stage of this disease is shown in Figure 9. The spots are not sharply defined, as in the spot blotch of barley, but

Fig. 9.—Helminthosporium leaf spot of oats.

gradually merge into the yellow or reddish tints which later may extend to a larger part of the leaf. Heavily infected leaves may die, and in this event the coloration changes from reddish to pale yellow or gray. At this stage of the disease, the spores of the causal parasite are produced on short stalks over the affected leaf surface.

From the dead leaves, the spores are carried to other leaves of the same plant or to nearby plants, thus spreading infection. The heads may also be infected, the parasite penetrating into the hull of the oats. Oat kernels affected with the leaf spot, show distinct browning at the basal end. When such kernels are planted and soil and weather conditions are favorable, diseased seedlings develop. The killing of the leaves and infection of the kernels results in light weight or shriveled grain.

Formaldehyde as applied by the sprinkling method for the control of oat smuts, page 21, reduces the amount of infection on seedlings. Certain experimental organic mercury dusts also have reduced the disease. Neither treatment entirely controls the leaf spot. Unless the disease assumes greater importance in local areas, routine seed treatments for the control of other diseases on oats will probably suffice.

Crown Rust of Oats

Puccinia coronata

Crown rust of oats, although prevalent throughout the State, seldom causes serious losses to the crop. The average annual loss due to this disease is considerably less than 1 per cent.

This rust is found principally upon the leaves, although it may also occur on the stems and heads. About heading time the rust appears as small, scattered elliptical, brownish yellow spots. This is the summer stage of the rust. Later, the winter or black stage appears surrounding the summer stage spots. The spring stages of the rust are not found on oats but require a different plant for their development, as does the stem rust of cereals. The spring stages of crown rust, however, are formed on species of buckthorn (*Rhamnus* spp.).

The life cycle of crown rust is similar to that of stem rust. The rust winters over in the black stage on infected oat stubble and refuse in the field. The teliospores (winter spores) produce sporidia which are blown to the leaves of nearby buckthorn bushes. Here the spring stages (pycnia and aecia) are formed. From the yellow pustules (aecia) on the under side of the leaves the spring spores, aeciospores, are blown to nearby oat plants. The aeciospores germinate and infect the oat leaf, producing the summer stage or uredinia. Several crops of the summer spores, urediniospores, are produced, each causing further infection until the oats begin to mature. At this time, the winter stage (telia), is formed, completing the life cycle of the parasite. Moist warm weather (60°-70° F.) is favorable for the rapid spread of the summer stage of crown rust and buckthorn bushes are essential to the initiation of early crown rust infection on oats in this state, since the summer stage is not known to survive the winter here. In southern states, the parasite passes the winter in the summer stage and it may be possible that some infection in this state may result from wind-blown spores from that source. Crown rust also attacks wild grasses such as blue joint grass, meadow fescue and velvet grass.

Early maturing varieties usually escape heavy infection. Eradication of

buckthorn bushes from the vicinity of oat fields should be practiced. Several varieties of oats resistant to crown rust have been developed by different experiment stations. Resistant varieties may be grown in localities where crown rust is so severe as to cause considerable annual losses.

Stem Rust of Oats

Puccinia graminis

The stem rust on oats often causes severe local losses in the state. The spread of the rust takes place from old infected oat stubble and refuse to the common barberry in the spring. From the barberry, infection spreads to oats and certain wild grasses, including wild oats and orchard grass. The stem rust of oats does not infect wheat, rarely barley or rye, and vice versa. This accounts for the fact that a crop of wheat near rusted barberries may show heavy rust infection but when oats are planted in the same field they remain free of the disease. This form of the stem rust is known as *Puccinia graminis avenae.*

The appearance of the disease and life cycle of the rust are quite similar to those on wheat, page 13.

Varieties of oats such as Richland and certain crosses between Green Russian and Richland show marked resistance to the oat stem rust. In Michigan, the variety Iogold in 1931 especially, showed marked resistance to the stem rust of oats.

Halo-blight of Oats

Bacterium coronafaciens

Halo-blight of oats is relatively an unimportant disease in Michigan, but under favorable conditions may cause appreciable damage to the crop in localized areas.

This disease is typically a leaf blight but may also affect the leaf sheath and glumes. The spots on the leaves at first are small, oval and slightly yellow-green in color. With the further development of the causal bacterium in the leaf tissue the spots enlarge and the center of the lesion becomes gray-brown in color. The green color of the leaf immediately surrounding the spots becomes yellow, forming a halo around the point of infection. In old spots there may be several yellow haloes, one within the other giving a target board effect. When several infected areas coalesce, general yellowing of the leaf results. Similar oval yellow spots are induced upon the glumes.

The halo-blight bacteria live over winter on the seed, and infect the young seedling. At first, the diseased spots are confined to the first leaf of the seedling but gradually they spread to other leaves, leaf sheath and to the heads where the grains are attacked. Natural infection may also occur on rye.

This disease is almost entirely prevented by the treatments used in the control of oat smuts, page 21.

Scab of Oats

Gibberella saubinetii

The scab of oats, because of the hull covering the kernel, is not so easily seen as the disease on wheat but the effects of the fungus are the same. Browning of the base of the kernel in light attacks and production of the dusty pink fungus growth are typical of the disease. Oat scab also affects the seedlings, Figure 10, causing reddish-brown decayed areas on the underground parts of the plant. The formaldehyde treatment (sprinkling method) and dust treatments as recommended for the smuts are effective in the control of this disease on the seed. Seed treatment will not prevent head blight. A more detailed discussion is given under wheat scab, page 11.

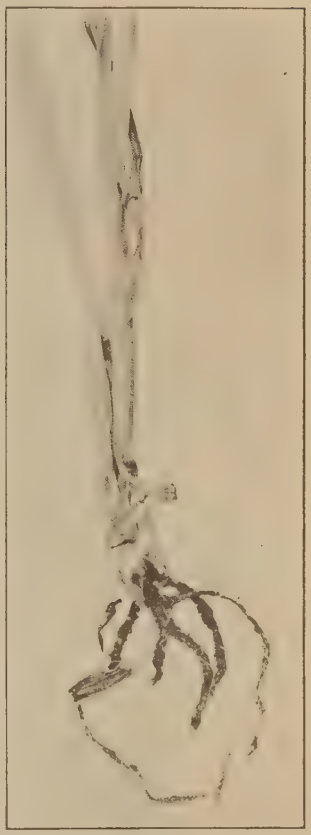

Fig. 10.—Oat seedling showing scab lesions on the roots.

Powdery Mildew of Oats

Erysiphe graminis

Powdery mildew of oats is caused by a specialized form of the fungus causing the disease on wheat. For a discussion of the disease, see page 17.

Ergot of Oats

Claviceps purpurea

Ergot of oats is found occasionally in the State but the percentage of infection is so small that the disease is economically unimportant. A discussion of the disease on rye and methods of control is given on page 39.

BARLEY DISEASES

Covered Smut of Barley

Ustilago hordei

This disease, affecting only barley, is annually present throughout the State where the crop is grown. Losses may range from a trace to 25 per cent in individual fields. For the entire State, the average annual loss is probably not over one per cent of the crop.

Covered smut is first seen about a week or ten days after the barley is in blossom. Smutted heads usually push out of the leaf sheath later than healthy heads or, failing to emerge normally, they break out at the sides of the sheath. At first the smutted heads appear healthy, but later, they become darker. This is due to the presence of the smut fungus which replaces the kernel and the glumes. The whole smut mass is covered by a gray membrane which persists until threshing. In threshing, the membrane is broken and the smut spores are scattered over the healthy seed. Plants affected with covered smut are shown in Figure 11.

When infected seed is planted, the smut spore germinates at the same time as the seed. The smut fungus then penetrates into the tissue of the young seedling, keeping pace with the growth of the plant until at heading time the fungus replaces the barley kernel with a black mass of spores.

Control of barley covered smut may be effected by hot water, formaldehyde, or organic mercury dust treatments.

The hot water treatment, page 30, is rarely used for this disease and then only when the seed to be treated is known to harbor also the loose smut. In such cases, only a small quantity of seed is treated sufficient to plant a seed plot.

Formaldehyde may be applied by any one of the three following methods:

Concentrated Formaldehyde Method—The barley seed is sprayed with the concentrated solution as it is shoveled from one pile to another. One pint of formaldehyde will treat 50 bushels of grain. The formaldehyde may be applied in full concentration or diluted with one or two parts of water. If less than 50 bushels of grain are to be treated, use correspondingly smaller amounts of formaldehyde. After spraying the correct amount of formaldehyde, shovel the treated grain into a pile and cover **four hours** with clean or disinfected bags or a blanket, then spread out into a thin layer and air thoroughly in a warm place. Rake the grain at intervals to assist in drying and plant at once.

Sprinkling Method—One pint of formaldehyde is added to 40 gallons of water and this solution is used at the rate of two quarts to the bushel for sprinkling the grain. A clean place on the barn floor is first sprinkled with

the solution and a four-inch layer of grain spread upon it. Sprinkle the layer of grain using two quarts of solution to the bushel. Add other layers of grain repeating the sprinkling. Shovel the treated grain into a pile and cover as above for two hours. Spread out into a thin layer to dry. Do not allow the grain to mould, sprout, or freeze. Plant as soon as the grain is dry enough to run through the drill. Allow for the swollen condition of the seed in sowing.

Soaking Method—The grain may be soaked in the above solution for 30 minutes, the solution drained off, and the seed covered for two hours. Spread in a thin layer to air and plant as soon as the seed will run through the drill.

With the hot water and formaldehyde treatments cracked grain will be injured to the extent of the injury in threshing.

Fig. 11.—Covered smut of barley.

Organic Mercury Dusts– Several organic mercury dusts have been tested for their effectiveness in control of covered smut of barley. Ceresan, the only organic mercury dust tested that is available in commercial form, gave as good results as the formaldehyde treatments. Ceresan is used at the rate of three ounces of the dust to one bushel of barley seed. The grain is placed in a tight container or mixer, Figure 2, the dust in appropriate quantity added, and the container rotated until each kernel is covered as in treating wheat with copper carbonate, page 6. The treated grain should be held in bags for at least five hours before planting. This treatment has the advantage of also controlling the seedling stages of stripe and spot blotch as well as reducing net blotch of barley. It is not effective against the loose smut of barley. Dusted seed may be kept for weeks without injury to germination.

Ceresan is poisonous and should be kept out of reach of children. Grain treated with Ceresan cannot be used for food or feeding purposes.

Loose Smut of Barley

Ustilago nuda

Loose smut, while widespread in the State, seldom causes a loss of over 2 per cent in individual fields.

The disease is first evident on the affected heads as they push out from the leaf sheath. At first, the brown smut masses which have replaced the kernels, may be covered by a thin membrane. This membrane early falls away leaving the powdery mass of spores. Rain and wind soon scatter the spores and there remains only the empty rachis. Although loose smut of barley is very similar in cause and appearance to the loose smut of wheat, it affects only barley.

Infection usually, but not always, takes place through the barley flower. The powdery spore mass in affected heads is blown or carried to healthy flowers of neighboring plants. Here the spores germinate and send the germ tube into the developing barley kernel. When the fungus has penetrated into the young kernel, it becomes dormant until the barley seed is planted. The fungus starts growth with the germination of the affected seed, keeping pace with the growth of the plant until heading time. With the formation of the seed, the fungus increases its activity, replacing the kernel and glumes with a mass of smut spores as shown in Figure 12.

In some cases, the spores may fall between the glumes and the kernel and remain viable until the seed is planted the following spring. In such cases seedling infection results.

Because the fungus causing loose smut usually lies dormant inside the seed, the ordinary methods of seed treatment cannot be employed. Although soaking in formaldehyde solution (one pint to 40 gallons of water) for 10 minutes and covering 10 to 12 hours has been recommended in some states for certain six-rowed winter barley varieties, it has not been proved effective on all six-rowed spring barleys.

At present, the hot water treatment is the most effective control of loose smut of barley. Because of the small percentage of infection in our standard varieties and the injury to cracked seed from this treatment, it is usually employed only when a loose-smut free seed plot is desired. The treatment is essentially the same as that for loose smut of wheat.

Place two pecks of cleaned seed in a coarse burlap bag tied at the top. Soak four hours in cold water and immerse for one or two minutes in warm water at about 120° F. Remove, drain and soak for thirteen minutes in hot water kept constantly at 126° F. or for fifteen minutes at 125° F. If the temperature falls below 125° F., the treatment is not effective; if it is higher than 129° F., the barley seed will be injured.

Spread the seed in a thin layer and dry as quickly as possible. Do not allow the seed to mould, sprout or freeze. Cracked kernels will be killed by this treatment and from one to two pecks additional should be seeded per acre.

Fig. 12.—Loose smut of barley.

Barley Stripe

Helminthosporium gramineum

Barley stripe probably occurs to some extent each year in Michigan, although it is seldom a serious disease except in restricted localities and upon certain varieties. Individual fields of barley showing 10 per cent to 60 per cent infection have been observed but the disease usually is much less prevalent.

Barley stripe, as its name indicates, first appears as yellowish longitudinal streaks on the leaves. The first leaves, then succeeding leaves produced,

show the typical striping, as shown in Figure 13. Later, redish brown stripes appear along the edges of the yellow streaks. The yellowed tissue dies and the leaf splits along the stripes or becomes shredded. There is a characteristic drooping to the affected leaves, and they become grayish-brown in color. Upon the dead striped tissue of the leaves the parasite produces its spores.

Affected plants are usually severely stunted, often attaining only half the height of normal culms. For this reason, diseased plants are frequently not noticed in the field. Usually, the spike fails to emerge from the leaf

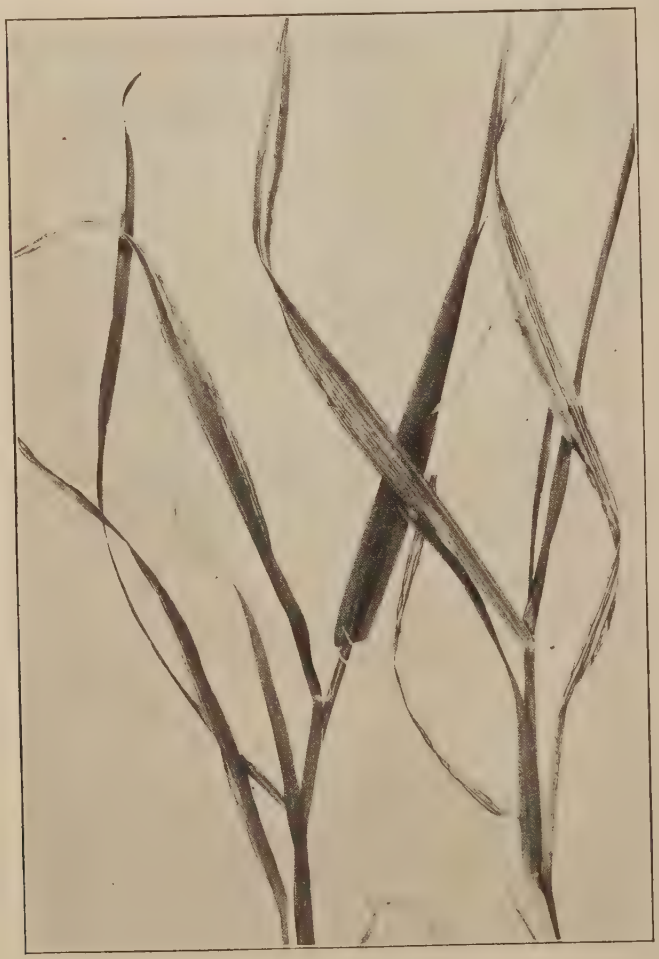

Fig. 13.—Barley stripe. Note longitudinal striping of the leaves.

sheath or may protrude from the side of the sheath, causing twisting of the head. The seed on such heads, if any is produced, is small, somewhat wrinkled, and light in weight.

The disease is spread by means of the spores upon the striped leaves being blown or carried to healthy barley flowers. Here, they germinate, penetrating into the young ovary. The fungus after infecting the kernel lies dormant until the seed is planted. With the germination of the seed, the fungus renews its growth, keeping pace with the development of the plant, finally producing its spores upon the infected leaves and thus completes its life cycle.

While the life cycle of the barley stripe fungus is much the same as that of the systemic loose smuts of barley and wheat, it is much less difficult to control. Seed treatments including both liquids and dusts have proved effective. The hot water treatment, page 30, will control the disease but is difficult to make. Soaking in formaldehyde solution will reduce the amount of infection in the seed but does not entirely control the disease. Sprinkling with formaldehyde as for oat smut treatment was not effective. Probably the most economical control measure from the standpoint of ease in handling and effect upon germination is the use of organic mercury dust. In our tests, one of these dusts, known as Ceresan, applied at the rate of three ounces per bushel, has given excellent commercial control. For method of treating see page 30.

Spot Blotch of Barley

Helminthosporium sativum

Spot blotch of barley is very common in Michigan, and has been known to cause serious reduction in stand and loss in yield. The disease is manifested as (1) leaf spot and (2) root rot or foot rot of seedlings and mature plants. In either case, the yield of affected plants is decreased.

Spot blotch first appears on the leaves as yellowish more or less circular or elongated spots, Figure 14. As the fungus progresses in the leaf tissue, the spots become darker, finally reddish, forming short, narrow dark brown streaks. Later, the whole leaf turns yellow, then grayish-brown and dies. Succeeding leaves may also be affected, causing death of the seedling. In case of less active invasion by the parasite, the plants may reach maturity, but because of the reduced green leaf area the seed may be light in weight. The barley head is also attacked, brown discolorations appearing on the glumes and on the basal end of the seed.

Root rot or foot rot appears early in the seedling stage. Reddish-brown to black lesions are produced on the roots, and foot of the young plant. The seedling may not emerge from the ground or only the tips of the leaves push out before they are killed. In some cases, the affected seedling is so stunted that the bases of the first leaves are not pushed above ground. In 1930 reduction in stand of 34 per cent, due to the foot or root rot, was seen in one field in addition to 60 per cent of the seedlings showing spot blotch on the leaves.

The causal fungus, *Helminthosporium sativum,* lives overwinter in the soil as well as in and upon infected barley grain. When diseased kernels are planted, the fungus becomes active upon the germination of the seed, growing into the young root or leaves, causing the reddish-brown to black

spots. The fungus in the diseased spots produces large numbers of spores which, borne by the wind, serve to infect other plants. The fungus develops best in moist soil, and at fairly high temperature (80°-90° F.). The fungus does not thrive in cold dry soil.

Field experiments in several counties indicate that soil infection is not at present a serious factor. Infected seed is generally the source of the disease. Field experiments also show that in the absence of soil infection, the disease can be almost entirely prevented by the use of certain organic mercury compounds. Of these materials, Ceresan used at the rate of three ounces per bushel was the most effective, the disease being reduced to one-half of 1 per

Fig. 14.—Spot blotch on barley leaves.

cent. In making the dust treatment, place the grain in a tight container, add the required amount of the dust, rotate about 50 times so that each kernel is completely covered with a thin layer of the chemical. The treated seed may be held for several weeks without injury.

Net Blotch of Barley

Pyrenophora teres

Another disease found in practically all barley fields in the state is net blotch. It is difficult to determine the actual damage caused by this disease, but it is safe to say that the yield is appreciably reduced thereby.

Net blotch affects the leaves, stems, and seeds of the barley plant. The disease first appears on the leaves as small, almost circular dark brown spots, Figure 15. These may increase in length to a short narrow streak. The elongated spots of net blotch are distinguished readily from those caused by stripe. Net blotch does not cause splitting of the leaves and the lesions on the leaves are much shorter than in stripe. Within the net blotch leaf spot, the brown pigment is distributed in transverse as well as longitudinal rays, presenting a reticulated pattern not found in the stripe or spot blotch lesions. In some cases, the net blotch spot appears to be made up of a network of fine brown lines. The leaf tissue surrounding the lesions is often slightly yellowed. As the fungus develops within the spots, the color fades from dark brown to brownish-gray.

The conidia or summer spores of the fungus, known in this stage as *Helminthosporium teres*, are produced upon the leaf spots as a grayish powdery coating. Scattered by wind, these spores which are produced throughout the growing period of the barley, spread infection to leaves, stems and heads of neighboring plants. Conidia falling upon the heads germinate, infecting the glumes. Within the tissue of the glumes, the fungus remains dormant until the seed germinates, when the parasite again becomes active, infecting the young plant.

The winter stage of the fungus known as *Pyrenophora teres*, is found upon old infected stubble and barley straw. Here, the fungus produces small, black flattened, flask-shaped bodies, the perithecia partially covered by the outer tissue of the stem. Within these bodies the winter spores (ascospores) are produced. In the spring or early summer they are shot out from the perithecia, fall upon the young plant, and produce infection. In addition, conidia are also formed upon certain stalks growing out from the perithecia. These also may account for some of the early infection. The relation of these two winter stages of the fungus to field infection is not clearly known. Probably the most important source of infection is diseased seed.

The fact that the causal fungus winters over on old straw and stubble and also within the seed makes control of the disease more difficult than that of either spot blotch or stripe. Rotation of crops so that barley will not follow barley, deep plowing to bury the infected stubble and straw, and seed treatment will materially lessen primary infection. Seed treatment as for stripe or blotch, using organic mercury dusts has been found of considerable benefit, but does not entirely control the disease. A few seeds, harboring the fungus internally, give rise to sufficient diseased plants to spread infection over a wide area, should weather conditions be favorable. In such cases, however, the delay in the spread of the disease may prevent serious losses

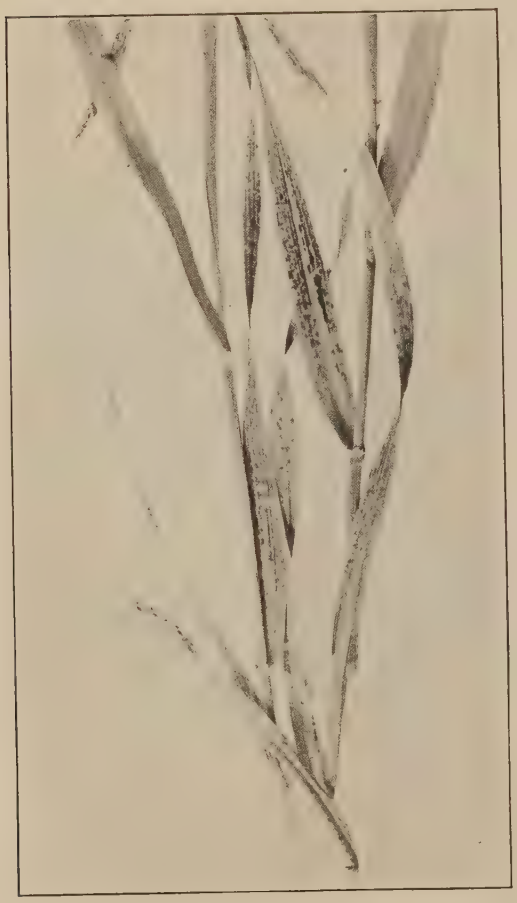

Fig. 15.—Net blotch on barley leaves.

which might have occurred had no treatment been applied. The hot water treatment as for loose smut of barley will control this disease.

Scab of Barley

Gibberella saubinetii

Scab on barley occurs throughout the State. At times, as in 1928 and 1929, the disease causes severe injury and loss in localized areas. Certain varieties, such as Black Barbless and Coleless, are very susceptible. Generally speaking, the smooth awn varieties are more susceptible than

the Manchurian types. In Michigan, Spartan barley shows some resistance to the disease.

Barley scab is caused by the same fungus which infects wheat, rye, corn, and to a lesser extent oats. The disease on barley shows symptoms quite similar to those of wheat scab. In barley, scab is not so evident as on wheat, because of the hull covering the kernel. Infected hulls become light brown in color; the kernels become gray. The fungus, over-running the infected kernel produces typical reddish, dusty, mycelium and spores of the summer stage, Figure 16A. Scattered over the kernel may be found the black perithecia of the winter stage of the parasite, Figure 16B. Infected kernels are shrunken, rough, and light in weight.

Fig. 16.—Scab on barley seed. A. Conidial or summer stage. B. Black perithecia of the winter stage.

Barley is becoming more generally used for feeding purposes within recent years. Considerable quantities of the grain brought into the state for feed in 1929 showed scab infection. Scabby barley, if fed in quantities, may be injurious, especially to swine. Reports from other states show that serious loss in weight of hogs may result from the feeding of barley showing 10 per cent badly affected with scab.

The control measures recommended for wheat scab, with the exception of seed treatments, should be used for the disease on barley. It is important that varieties adapted to the soil and locality be sown. If scab alone or scab and covered smut are present either formaldehyde or Ceresan may be used to treat the seed. If scab, covered smut and stripe are present Ceresan should be used, since formaldehyde is not so effective against the stripe disease.

The formaldehyde treatment consists in soaking the seed 30 minutes in a solution made by adding one pint of formaldehyde to 40 gallons of water. After soaking, cover the grain in piles with clean bags for two hours. Spread the treated seed in a thin layer, rake frequently until dry enough to run through the drill. Do not bag the grain while damp.

Ceresan is used at the rate of three ounces of the dust to each bushel of grain. Mix thoroughly by rotating in a tightly closed container, Figure 2.

Powdery Mildew of Barley

Eryspihe graminis

This disease is identical in symptoms and cause with that on wheat. Because of the extreme specialization of the fungus, however, the disease on barley cannot spread to wheat, oats or rye. For additional discussion see page 17.

Stem Rust of Barley

Puccinia graminis

This rust occurs throughout the state, becoming epidemic occasionally. Usually the annual loss due to stem rust does not exceed one per cent of the crop.

The appearance of the disease on barley is very similar and the life cycle of the parasite is identical with that on wheat. A detailed discussion of the disease on wheat is given on pages 13 to 16.

Leaf Rust of Barley

Puccinia anomala

The leaf rust of barley is of small importance in Michigan but may under favorable conditions cause local losses of one per cent or more.

The disease appears on the barley leaves as small, oval, light yellow spots. Both upper and undersides of the leaves may be affected. These spots contain the summer spores. The winter spores are formed in grayish patches, usually running together to form an elongated lesion. It is thought that the rust passes the winter also in the uredinial or summer stage. The winter spores infect Star of Bethlehem (Ornithogalum sp.) producing aecia (spring stage). This stage of the rust is not known to be necessary to infection on barley.

Comparatively little work has been done with this rust and resistant varieties of barley are at present not known.

Ergot of Barley

Claviceps purpurea

This disease is found occasionally in Michigan, but is of no economic importance. The appearance of ergot on barley, Figure 17, is similar to that on rye. For discussion of the disease the reader is referred to page 39.

Fig. 17.—Ergot of barley.

RYE DISEASES

Ergot of Rye

Claviceps purpurea

Ergot is one of the most common diseases of rye. It is found to some extent in all parts of the State and upon all commercial varieties of this crop. Wheat is also affected and to a lesser extent both barley and oats, although seldom found in the latter crop. This disease is also quite common on various wild grasses including quack grass *Agropyron repens* wi'd barley or squirrel-tail grass *Hordeum jubatum*, wild rye *Elymus canadensis*, brome grass *Bromus inermis*, orchard grass *Dactylis glomerata*, meadow fescue *Festuca elatior*, the blue grasses *Poa pratensis* and *P. compressa*, meadow foxtail *Alopecurus pratensis*, and numerous other species of the Gramineae. It has been definitely proved that the ergot of sweet grass, meadow foxtail, reed canary grass, orchard, Kentucky blue, and brome grasses, perennial rye grass, and quack grass will also infect rye. The relation of the fungus on other grasses to rye infection is imperfectly known.

The ergotized grains contain poisons causing under certain conditions "Ergotism," known as a serious disease in cattle, horses, mules, sheep, hogs, and fowls. The disease is less common in man.

Ergot of rye is recognized in ripening grain by the hard, violet or black, horn-like bodies which replace the normal kernels in the head,

Figure 18A. These are the sclerotia or resting bodies of the causal fungus. In this form, the fungus lives over winter on the ground where the sclerotia are scattered in harvesting or they are mixed with the grain in threshing and are planted with it. In either case, they find their way back to the soil. Living over winter in the soil the sclerotia germinate by sending out very thin small stalks surmounted by globular heads which appear just above ground, Figure 18B. Embedded in the heads are small sac-like structures which contain the winter spores

Fig. 18.—Ergot of rye. A. Ergots or sclerotia replacing kernels in the heads. B. Germinating sclerotium.

(ascospores) of the fungus. These spores are shot out into the air, and are carried to the flowering grain where they produce the primary infection. Falling upon the open flower the spore germinates, infecting the young ovary and filling it with a moldy growth. Sometimes the flowers are entirely destroyed causing "blasting" of the heads. Further growth of the fungus results in the formation of a spongy mass in place of the normal kernel. The spongy mass of fungus threads gives rise to millions of summer spores or conidia (the sphacelial stage) which are carried to the surface of the flowers in a slimy, sweet, cloudy, liquid called "honey dew." Insects visiting infected flowers become carriers of the conidia to healthy heads thus causing secondary infection. The fungus mass enlarges, darkens to a reddish or violet color, finally becoming black when hardened and mature. In the mature stage, the black sclerotium is usually more angular and longer than a normal kernel, curved somewhat and with longitudinal and transverse cracks.

Warm temperature with abundant moisture is necessary for the germination of the sclerotia in the soil. Moist weather at heading time is also essential to the infection of the rye flowers. Dry weather during this period to a large extent prevents infection.

Control of Ergot

The parasite is carried over from crop to crop as sclerotia or black resting bodies in the soil where a previous diseased crop was grown or sowed with the seed. The planting of crops, not cereals or grasses, for two or three years will control soil infestation by the fungus. Deep plowing is also advised. Grasses known to be infected should not be allowed to grow near rye fields. In addition, the ergot sclerotia should be removed from the seed. Ergotized kernels are lighter in weight than normal rye kernels. The seed to be treated is poured into a tub or half barrel containing a solution of common salt. Make up the solution by adding 40 pounds of salt to 25 gallons of water. When the salt is dissolved, pour in the grain and stir thoroughly. The light kernels and the ergot sclerotia will float and can be skimmed off. Wash the clean grain (that left in the solution) in clean water. Even a small quantity of salt left on the seed will injure germination. Dry thoroughly if the grain is to be treated with copper carbonate for stem smut or held for planting.

Rye Smuts

There are three smuts of rye, two of which are very seldom seen, and the third found only occasionally in Michigan.

Stem Smut of Rye

Urocystis occulta

This smut is first seen just before the heads are coming out. Diseased plants are darker green than normal and the infected stems or leaves are usually twisted, distorted, or split open by the fungus within the tissues of the plant, Figure 19. At first, the disease is noted causing lead colored streaks on leaves or stems. These streaks turn black due to

the presence of the black spore masses of the smut fungus. Frequently, infection may be found in the glumes. Due to the stunting and twisting of diseased plants, affected plants are frequently overlooked in the field, and the disease is passed unnoticed.

After the fungus breaks through the plant tissue, the dusty spores are blown to the heads of neighboring healthy plants. Here, they lie dormant until planting time. Spores also may fall to the ground where they lie dormant until the fall rains cause them to germinate. Infection of rye may result from spores scattered at heading time on the

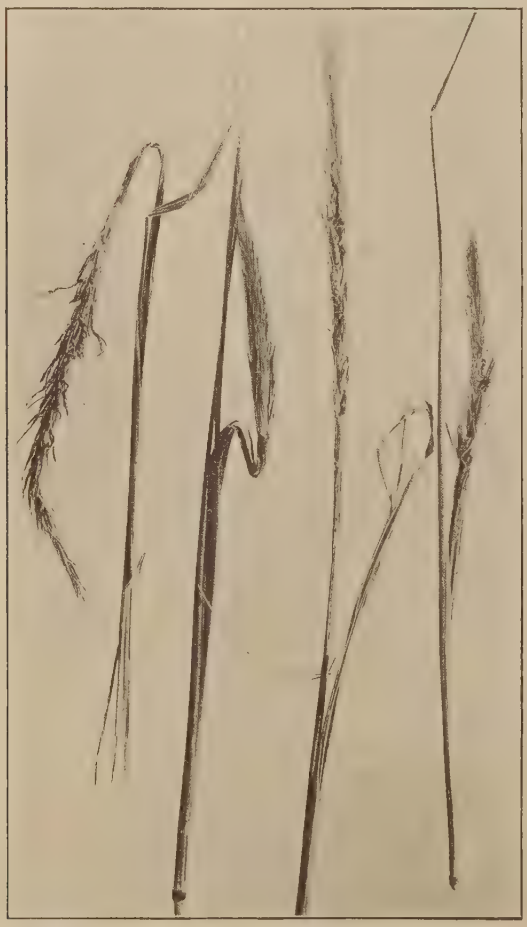

Fig. 19.—Stem smut of rye. Note black smut streaks on leaves and stem and twisting of the heads.

seed or from planting clean grain in contaminated soil. In this State, the spores in the soil are not usually a source of infection, because they germinate and die before the rye is sown. Seed contamination is the main source of the disease. The surface borne smut spores germinate when the seed germinates, causing infection of the seedling. Growing upward through the stem or leaves, the fungus breaks through the tissue of the plant exposing the typical spore mass as seen just before and during the heading out of the rye.

This smut carried on the seed is readily controlled with copper carbonate at the rate of three ounces of dust to each bushel of grain. Apply as in wheat treatment, page 6. Formaldehyde treatments as for stinking smut of wheat, page 8 are also effective, but must be used with care to prevent injury.

Stinking Smut and Loose Smut of Rye

Tilletia levis—Ustilago tritici

The stinking smut and loose smut of rye are caused by the same fungi which are responsible for these diseases in wheat. The treatments for their control are also the same as those for wheat, and the reader is referred to pages 4 and 9 for their discussion. In Michigan, these two diseases are of no economic importance.

Stem Rust of Rye

Puccinia graminis

Stem rust on rye, while common, seldom causes serious loss to the crop. The rust parasite in this case is known as *Puccinia graminis secalis* and does not naturally infect wheat nor oats but may attack barley and wild grasses and especially quack grass. The spring stages of the rust are formed on the common barberry with the summer and winter stages on rye. The life history of the parasite and appearance of the disease on rye are similar to those of the stem rust of wheat, page 13.

Spot Blotch of Rye

Helminthosporium sativum

This disease is sometimes observed on rye but appears to be of no economic importance in the growing of the crop in Michigan. However, in the midwestern states it may assume serious proportions in years favorable for its development.

The symptoms of the disease on rye, methods of spread and means of control are the same as for wheat, page 16, and barley, page 33.

Powdery Mildew of Rye

Erysiphe graminis

Powdery mildew of rye is similar in all respects to the disease on wheat. The fungus causing the disease on rye, however, will not affect oats, barley, or wheat. For a further discussion of symptoms, life history, and control refer to page 17.

Leaf Rust of Rye

Puccinia dispersa

This rust is found annually throughout the State where rye is grown. Locally the disease may cause considerable loss, but for the state as a whole damage to the crop probably does not average 1 per cent.

On the leaves and to some extent the stems, small oval brown spots appear. As the rust develops, it breaks through the epidermis exposing the reddish-brown mass of summer spores, urediniospores. The rust is spread throughout the growing season by means of the summer spores. New crops of spores and new infections may occur every seven to ten days under favorable weather conditions.

The winter stage occurs as small, elongated, grayish spots covered by the epidermis. The winter spores, teliospores, are known to germinate in the fall or they may remain over winter and infect the alternate host plant, *Anchusa sp.* producing the spring stage. This stage is seldom seen in the United States. The relation of the spring stage to infection is not known. The rust also over-winters in the summer or uredinial stage.

Investigations carried on at the Indiana Agricultural Experiment Station indicate that a strain of Abruzzes rye is resistant to leaf rust.

Scab of Rye

Gibberella saubinetii

Scab of rye shows almost identical symptoms with this disease on wheat. Rye kernels only partly infected become dark brown, while those badly diseased are carmine red in color. Diseased kernels are shrunken, wrinkled, and have a rough surface. On seedlings, the disease is quite similar to the blight on wheat and barley. Ceresan, an organic mercury dust, has been found an effective treatment. Apply this treatment as for wheat scab, page 11.

CORN DISEASES

Corn Smut

Ustilago zeae

Smut or boil smut is one of the most common and conspicuous diseases of corn and under favorable conditions may cause considerable loss to the crop.

The disease may be found upon any of the aerial parts of the corn plant. It is first evident as a small raised almost white pustule. As the smut fungus develops, it stimulates the plant tissue to increased growth. Later, the color of the pustule or boil darkens due to the presence beneath the tumor membrane of the black spore masses of the fungus. Smut infection on the ear and tassel are shown in Figures 20 and 21. There may be considerable variation in the size of the smut boil due to the effect of weather conditions upon growth of the parasite and affected plant as well. When the fungus has reached maturity within the boil, the plant tissue membrane enclosing the spore mass

dries and ruptures exposing the black powdery mass of spores. The spores fall to the ground or may be carried considerable distance by wind. The spores in the smut boil may remain viable for five to seven years.

With sufficient moisture, these spores germinate sending out a short stalk, which bears secondary spores, the sporidia. Further infection of young rapidly growing tissue of the corn plant takes place by means of the sporidia which are blown to the corn plant. The germinating sporidia send out infection threads which penetrate the tissue of the corn plant giving rise to new smut boils. After falling from the smut boil to the ground, the spores may remain dormant and viable in the

Fig. 20.—Smut on corn tassel.

soil for at least a year, providing the source of infection for succeeding crops of corn. The feeding of smutted fodder, while usually having no deleterious effect upon cattle may also serve to spread corn smut. While corn smut spores are largely killed by passage through the alimentary tract of farm animals, portions of the smut boil may become mixed with the litter of the stall and find their way to the manure pile and thence to the field.

Control measures must take into consideration the fact that corn

Fig. 21.—Smut on corn ear.

smut is carried over from year to year in soil, manure, and crop refuse. Keeping such material from the field, and proper rotation help to reduce infection. Yearly selection of seed ears from smut-free plants also aids in reducing the disease. Since resistance to smut is inherited in corn, highly resistant strains may be developed by proper selection and by breeding.

Corn Rust

Puccinia sorghi

The rust of corn occurs throughout the State but seldom causes any serious damage on field corn. However, on certain varieties of sweet corn, rust infection may be so severe on some plants as to prevent ear formation. It is typically a leaf disease.

The disease first appears on the leaf as elongated raised blister-like pustules slightly yellowish in color as contrasted with the normal green of the leaf. The leaf tissue covering the pustule dries out, becomes brittle and breaks, exposing the reddish brown mass of rust spores beneath, Figure 22. This is the summer or uredinial stage of the fungus. Later in the season, the dark brown winter spores or teliospores appear within the same pustules which then are almost black. The spring stage of the rust (pycniospores and aeciospores) is found on species of Oxalis (wood sorrel).

The aeciospores produced on several species of sorrel are blown in the spring to the corn plant. Here, they germinate, and infect the leaf giving rise to the summer stage in which the reddish brown urediniospores are formed in pustules. These summer spores are blown about the field causing further infection and producing more rust pustules. Later in the season, the teliospores of the winter stage are produced in the same pustules. These spores cannot infect the corn plant. They live over winter on the infected corn leaves on the ground and in the spring germinate and produce secondary spores or sporidia. The sporidia are carried by wind or otherwise to the leaves of the wood sorrel and other species of Oxalis where they cause infection and reproduce the spring stage with its pycniospores and aeciospores, thus completing the life cycle of the rust fungus.

Although corn rust is prevalent in Michigan it has not assumed sufficient seriousness to warrant investigations of control methods. It is known however that certain strains or crosses of corn are highly resistant to rust. This offers a basis for breeding work should the disease become a serious pest.

Gibberella Ear Rot

Gibberella saubinetii

This disease, while most conspicuous on the ear, also causes stalk rot and seedling blight. The disease may be locally important under favorable conditions but has not been reported as wide spread and severe in the state. Those weather conditions favoring scab development on wheat, (page 11), barley, (page 36), rye, and oats are also conducive to infection by the ear rot fungus.

On the ear, the disease is evident as a pink to red moldy growth over and between the kernels. This is the summer or Fusarium stage

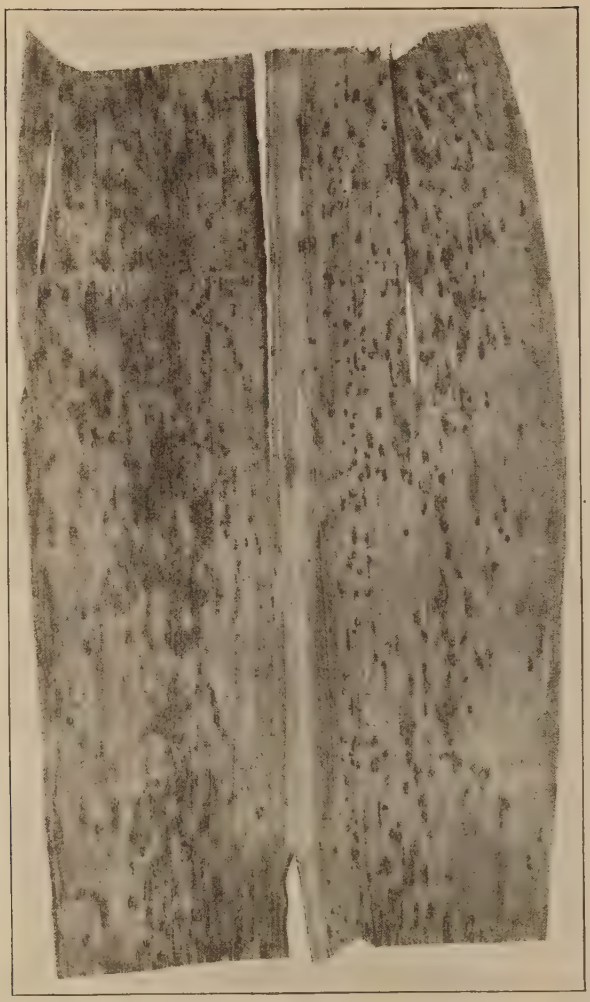

Fig. 22.—Leaf rust of corn.

of the fungus. Infection typically takes place at the tip of the ear and progresses evenly downward toward the butt end. Heavily infected kernels, Figure 23A, are killed but those only lightly infected may not show evidence of the fungus until germination tests are made. This procedure may fail to reveal slight infection where the temperature of the germinator is kept at about 75° F., but if such seed is planted in cool wet soil, the fungus may cause considerable damage.

When badly infected seed is planted, poor stands result from failure to germinate. If only slightly infected seed is planted in cool wet soil, the fungus attacks the basal portion of the plant producing a dark brown rot. Infected plants which survive, are stunted and weak. In later plantings, in warm soil, little loss in stand or vigor of plants may result. The late stages of the disease are especially noticeable near the nodes on corn stubble or old stalks left over winter in the field. This is the winter stage of the fungus and it appears as small black dots, the perithecia, scattered over the infected surface, Figure 23B. This fungus also causes scab of wheat, barley, rye and oats and produces identical fruiting bodies on these grains, see pages 11 and 36.

The fungus lives over winter in the perithecia on infected corn stalks and stubble and on refuse from small grain crops, principally wheat and barley. It may also live over on infected ears discarded during

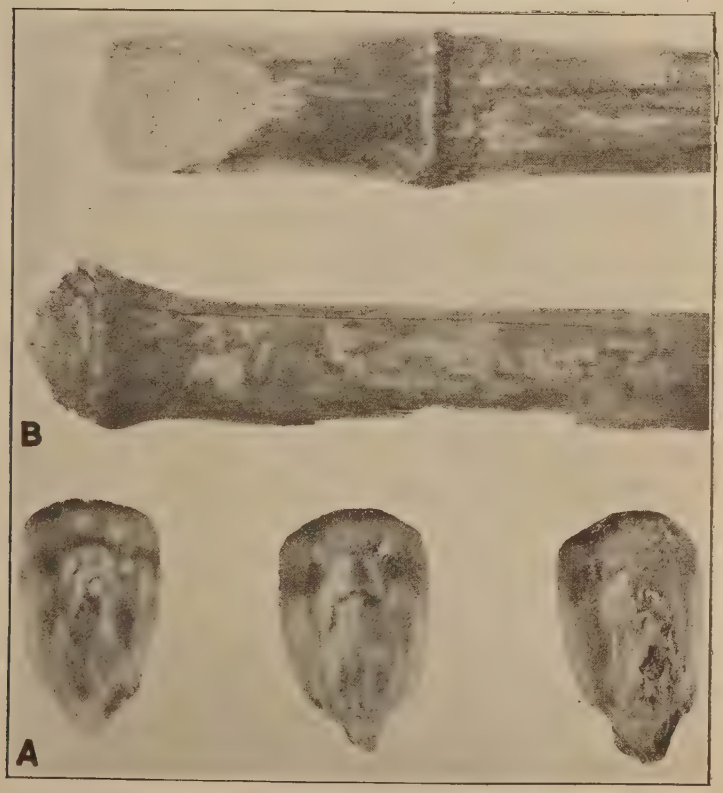

Fig. 23.—Gibberella ear-rot of corn. A. Kernels showing moldy growth of the summer stage of the fungus. B. Perithecia of the winter stage at the nodes of corn stubble.

harvesting. The perithecia, appearing as black dots on the corn stubble and stalks, contain numerous ascospores of the fungus which are released and scattered about the corn and small grain fields during the growing season. If the weather is moist and warm at this period, the spores falling upon the corn plant germinate and growing within the tissues produce stalk rot or falling upon the ear cause the ear rot. The disease also lives over winter on infected corn kernels; but, here, its development is underground and little or no dissemination of the fungus results. Spores from the perithecia on old corn refuse if blown or carried to small grains initiate scab infection under favorable conditions.

The plowing under of infected corn and small grain refuse is probably the most important control measure that can be practiced. However, such measures, on one farm, will not prevent spread of the disease from neighboring fields where infected refuse is left lying on top of the ground. Seed suspected of being infected slightly should be treated. For this purpose, one of the organic mercury dusts such as Semesan Junior, Sterocide, or Merko will be found effective, especially if the seed is planted early in cool moist soil. In later plantings when the soil is warm, little benefit will probably result from seed treatment. A rotation in which corn does not follow corn nor barley and wheat is also advisable. Careful selection of seed ears followed by germination tests is important in control of this disease.

Dry Rot of Corn

Diplodia zeae

Dry rot, although frequently observed in the State, rarely causes severe losses except in localized areas. Frequent periods of heavy rainfall during the latter part of August when the stalks have practically ceased growth appear to be favorable for growth of the dry rot fungus.

The disease is usually found affecting the leaf sheath, the ear and the stalk. It may also attack the roots and stalk of the seedling, resulting in weakened plants or entire rotting of the seedling.

Disease lesions varying in size and shape appear on the leaf sheath after flowering time. These spots are reddish or purple in contrast to the normal green color of the sheath and may extend downward into the node of the stalk or upward affecting the midrib of the leaf. When the corn plant is mature, these spots may still be seen as ashen gray areas surrounded by a darker border.

Any part of the ear is susceptible to attack. The causal fungus may gain entrance at the tip through the silks, growing downward beneath the husk and covering the kernels with a white moldy growth. In some cases, this mold-like growth penetrates the husk and may be seen from the outside. When the ear is attacked from the butt end through the shank, the disease may be apparent as a fine moldy growth between the kernels, or only visible after shelling as a fine white mold upon the kernel tips. This latter condition frequently occurs in ears with loose kernels, Figure 24A. In cases of light infection, the disease may escape observation until the corn is germinated, when the fungus appears as a white fluffy mold. The shank of the ear also may show the white mycelial growth of the fungus.

On the stalk, the disease may often be present as a white moldy growth beneath the sheath at the nodes or extending upward along the covered portion of the stem. The infected lower nodes often show water-soaked discoloration. Usually, the disease is not readily noticed until the fruiting bodies of the fungus appear on the stalk. These are small black pimple-like dots, the pycnidia or fruiting bodies of the fungus, and contain the spores which after passing the winter are able to infect the crop the following season. Figures 24B and 24C show the pycnidia of the fungus on the husk and on cob at the base of the kernels.

When infectel kernels are planted, they may fail to germinate and rot in the ground, the seedling may be killed or weak plants are produced. Plants from infected seed appear yellowish in color and are usually stunted, the latter effect being retained until maturity. When the seedling is attacked by the fungus in the soil, rotted areas develop

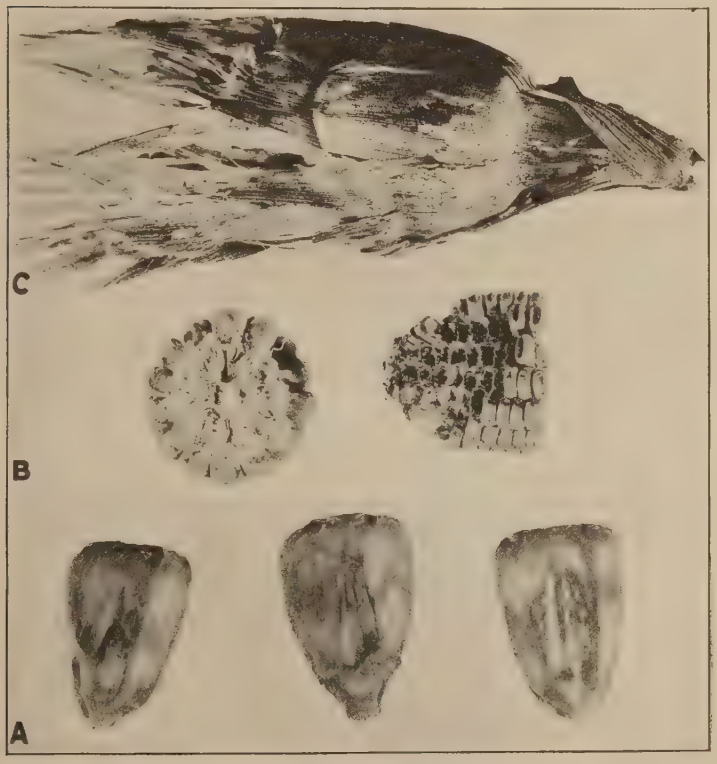

Fig. 24.—Diplodia dry-rot of corn. A. Characteristic streaking of the seed coat. B. Chaffy, infected kernels with black pycnidia of the fungus shown in cross section of cob. C. Pycnidia on husk at base of ear.

on the roots and the base of the stalk may show discoloration and rotting.

The principal source of infection is the old infected stalks. These when left in the field may serve as sources of infection for the crop for at least three years. The fungus may also live on the soil humus in the absence of corn refuse.

Early selection of seed corn from stalks showing no shank or ear infection and rapid curing in a dry well ventilated room is essential, in control of the disease. Germination tests should be made to detect slight infection. A rotation of four years, or longer where infected material has been plowed under, will also help to prevent the disease. Certain strains of corn also show varying degrees of resistance to the dry rot. Seed treatment with mercury dusts such as Merko, Semesan Junior, and Sterocide on slightly infected kernels has also been found beneficial especially in early plantings. However, ear selection and crop rotation are the more important practices to be followed.

Basisporium Dry-rot

Basisporium gallarum

This dry-rot is present to some extent each year and under favorable conditions may cause severe losses to the crop. While commonly associated with infection of the corn ear, the disease also affects the seedling, causing loss in stand and weakened plants of lessened productivity.

On the ear, Basisporium dry-rot is evident as a blackening of the kernel tip as well as the chaff and cob at the base of the kernel, Figure 25B. There may also be seen a scant moldy growth of the fungus between the kernels, most commonly at the butt of the ear. The characteristic blackening of infected kernels and cob is due to the black spores of the fungus which are borne in clumps closely appressed to the infected parts. Infected ears are light in weight and break easily either crosswise or longitudinally. Diseased kernels are light in weight, chaffy and when heavily infected may be grayish in color with the characteristic black spore masses at the tip, Figure 25A.

The shank of the ear is also attacked by the parasite, resulting in retting or shredding of this part of the plant. The causal fungus destroys the cellulose of the shank leaving only the vascular tissue intact. Ears broken from diseased shanks retain part of the shank tissue in the form of shreds, Figure 25C.

The fungus attacks primarily the germ of the seed often causing its death. Hence, the use of infected seed may result in severe loss in stand, especially when planting is done in cold soil and the fungus destroys the food material of the seed before the seedling has established itself on its own roots. With light infection, the disease may not be evident on the ear or dry kernel nor be apparent when the germination test is made. In such cases, weak plants that soon die or grow into unproductive stalks may result.

The dry-rot fungus, *Basisporium gallarum,* is present in the field on old infected corn litter from a previous crop. Spores of the fungus are blown to the growing plants, falling upon the shank or between the opening husks. Here they germinate and infect the shank, cob and

kernels. The fungus does not appear to attack vigorously growing plants but those which because of inadaptability to environment, injury from frost or other conditions are already weakened. High humidity late in the season appears to be essential to infection, while temperature is not of so much importance.

Control of Basisporium dry-rot includes those practices which make for successful corn production, including rotation, fertility and selection of varieties adapted to local growing conditions. In the selection of well matured ears of a suitable variety, those should be discarded which show infected kernels or those from shredded shanks. Germination tests will also reveal certain infected ears which otherwise might pass unnoticed. In such tests those kernels showing masses of black spores closely appressed to the seed coats should be discarded as diseased. Since lightly infected kernels may not always be distinguished either when dry or on the germinator, seed treatment with one of the

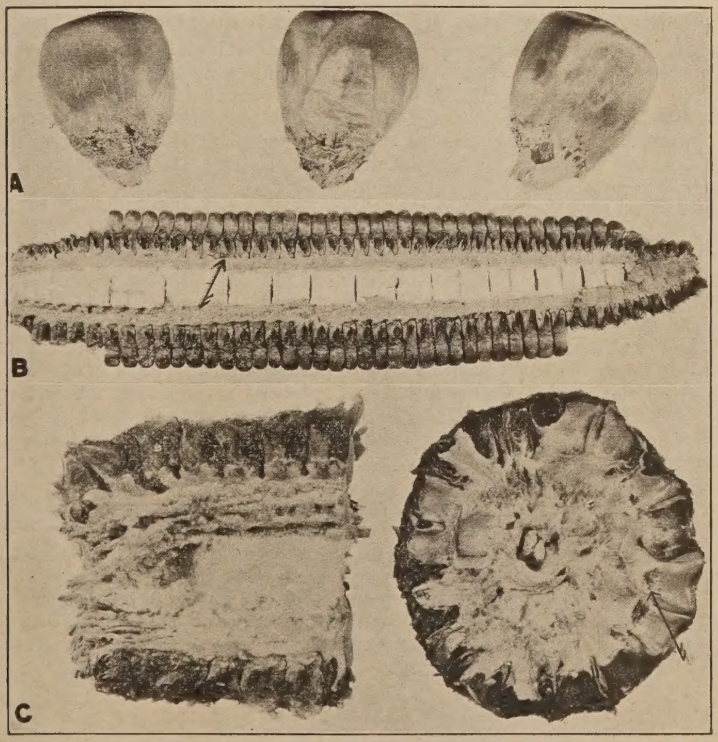

Fig. 25.—Basisporium dry-rot of corn. A. Black spore masses of the parasite on tips of kernels. B. Infected ear with black spore masses at base of kernels. C. (Left) Shredding of butt of cob and (right) spore masses of fungus on cob.

mercury dusts will aid materially in reducing loss in stand, especially if early planting in cold soil is done. For this purpose dusts such as Merko, Semesan Junior, or Sterocide, applied at the rate of two ounces to the bushel of shelled corn have been used to advantage.

Bacterial Wilt

Aplanobacter stewarti

Bacterial wilt or Stewart's disease is of no economic importance on field corn in this State but locally may cause severe losses in sweet corn. The disease so far is confined to the southern portion of the state. It is more severe on early than late varieties. Wet weather and high soil temperature at planting time favor the development of the disease. Dry weather later in the season hastens wilting of the affected plants.

The disease may appear at any time from the seedling stage to the formation of ears. As the name indicates, the principal symptom of the disease is wilting, first of the leaves and later the entire stalk in the young plant. In older plants, stunting frequently occurs, and the tassels while developing earlier than in normal plants are noticeably bleached. Leaves of older infected plants die gradually from the base of the stalk upwards. Death of the leaves progresses from the tip toward the base. Infection and death of older plants has sometimes been confused with burning due to the heavy application of fertilizer and lack of soil moisture. Pronounced wilting is not always observed on older infected plants.

While wilting and yellowing of the foliage, especially in young plants, may result from causes other than bacterial wilt, this disease may be almost certainly recognized by splitting open the stalk and examining the interior tissue. Plants affected with the wilt disease usually show yellow longitudinal streaks. The yellow streaks in the split stem are caused by the causal bacterium filling the vascular bundles. When the stalk is cut crosswise, the bacteria ooze to the surface as a yellow slime.

Infection spreads through the entire plant producing dark gray sunken areas on the seed. When such seed is planted in wet soil, the bacteria pass readily into the vascular elements of the plant and cause systemic infection. Infection may also take place when the causal bacteria are carried by insects (corn ear worm and flea beetle) from diseased to healthy plants.

Seed treatments are not entirely effective in controlling bacterial wilt. Soaking the seed 15 minutes in a solution of bichloride of mercury (1 oz. of bichloride of mercury in 7½ gallons of water) followed by thorough rinsing in fresh water may be of some benefit. Careful selection of clean ears from healthy plants and the use of late varieties for planting in fairly dry soil will aid materially in the control of the disease. It seems, probable that early varieties resistant to the disease might be developed by breeding.